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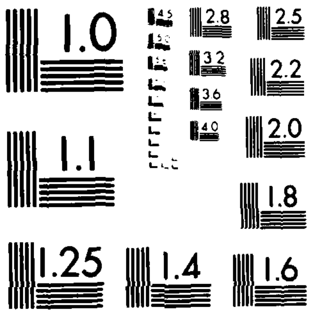

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REEVALUATION OF USAFSAM SAMPLING AND DATA-AVERAGING PROCEDURES FOR RESPIRATOR QUANTITATIVE FIT TEST

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June 1984

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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This final report was submitted by personnel of the Chemical Defense Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-03-05.

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USAFSAM Respirator Quantitative Fit Test methods, procedures, and data analysis capabilities have been reevaluated. Omission of test-tent sampling can result in errors in calculating the protection factor by as much as a factor of 2. The method of averaging protection-factor data over six or more exercises can also result in protection factors greater than those of other laboratories by as much as a factor of 2. An alternate method of averaging protection-factor data is being investigated.

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CONTENTS

List Of Illustrations

List Of Tables

REEVALUATION OF USAFSAM SAMPLING AND DATA-AVERAGING PROCEDURES FOR RESPIRATOR QUANTITATIVE FIT TEST

INTRODUCTION

Technical reports by Kolesar and co-workers [1,2,3,4] give details of the USAFSAM Respirator Quantitative Fit Test (RQFT) procedures. A schematic diagram of the sodium chloride RQFT instrument is shown in Figure 1. The sodium chloride test method, described by British Standards 4400 and 3928 [5, 6], has been adapted and modified by USAFSAM to measure protection factors in the respiratory and eye compartments of aircrew chemical-defense respirators [2]. This instrument generates a solid aerosol of sodium chloride crystals as the challenge atmosphere. The concentration of challenge atmosphere in an aircrew respirator is measured using a hydrogen flame photometer, and the result is displayed on a strip-chart recorder. The ratio of the challenge concentration to the respirator concentration is called a protection factor (PF).

$$\text{protection factor} = \frac{\text{concentration of challenge}}{\text{concentration in respirator}}$$

Recently RQFT protection factors reported by USAFSAM have been the subject of some controversy. In particular, USAFSAM reported PFs significantly greater than those reported by Los Alamos National Laboratory (LANL) for the same respirators (XM-30). The RQFT instrument and test procedures at USAFSAM have been reevaluated in an effort to find a reason for this discrepancy in PF data. Two procedures that affect the magnitude of reported average PFs were identified and investigated. Results presented in the next two sections show that part of the discrepancy is due to an incorrect procedure and part to differences in the definition of average PF. An alternate method of averaging is investigated.

AEROSOL EQUILIBRIUM CONCENTRATION AND LINE LOSS

It had been assumed [7] that NaCl RQFT measurements could be made after allowing about 3 minutes for the challenge concentration in the test tent to reach equilibrium. Theoretical calculations followed by experimental verification, however, indicate that the time required for the test-tent concentration to reach equilibrium is about 10 minutes. Measurements made from the respirator before equilibrium is established in the test tent are not valid because the concentration of the challenge atmosphere is less than the assumed value. A PF calculated from such measurements will be greater than the true value.

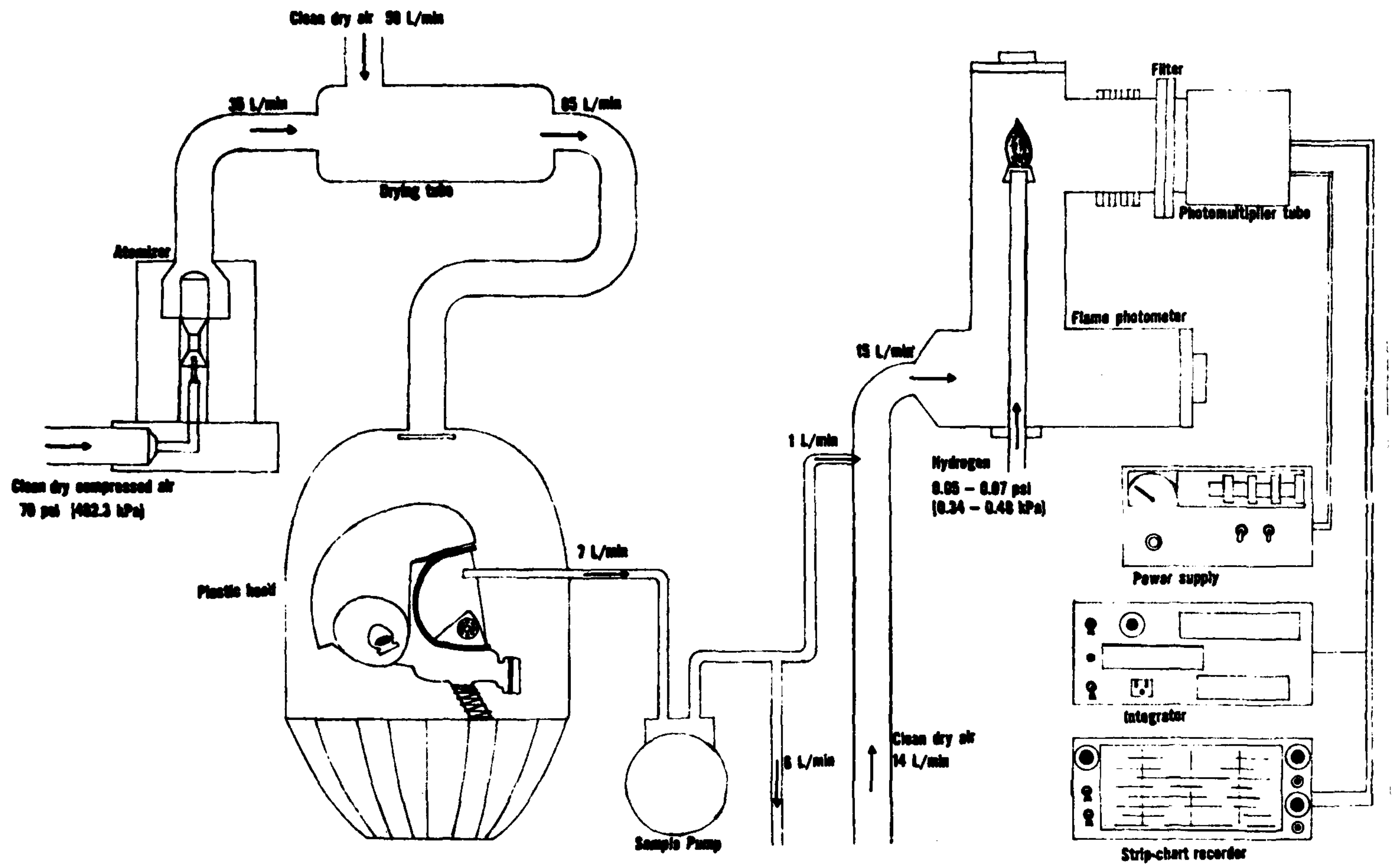

Figure 1. USAFSAM sodium chloride respirator quantitative fit test instrument.

It had also been assumed that (after equilibrium was reached) concentration measured from the test tent was equivalent to the concentration measured from a standard calibration aerosol, so the challenge concentration was not being measured from the test tent. The assumption is valid only if there is no aerosol line loss between the test tent and the detector. Recent data indicate that line loss cannot be ignored. Thus, samples taken from the respirator were subject to line loss while the assumed challenge concentration was not, leading to calculated PFs that were greater than the true value. That is,

$$PF = \frac{\text{challenge concentration + line loss}}{\text{respirator concentration - line loss}}$$

Figure 2 is a histogram of 39 test-tent concentration observations as a fraction of the standard-calibration aerosol concentration. The observations are the arithmetic mean of two measurements. One measurement was made 3 minutes after NaCl aerosol generation began, and the other after a PF test, approximately 10 minutes later. The observed test-tent concentration is generally less than half the calibrated aerosol concentration because of a combination of line loss and deviation from equilibrium challenge concentration.

CALCULATING AVERAGE RQFT PROTECTION FACTORS

A protection factor is defined as

$$PF = \frac{C_o}{C_i} \tag{1}$$

where C_o is the concentration of the challenge atmosphere and C_i is the concentration of challenge that penetrates into a respirator or other piece of personal protective equipment. In reporting PF data, an average, <PF>, is used to summarize the results for one test subject over several consecutive exercises. Authorities disagree on how to calculate average PF.

USAFSAM has used the definition [2]

$$\langle PF \rangle = (PF_1 + PF_2 + \ldots PF_N)/N \tag{2}$$

where $PF_1, PF_2, \ldots, PF_N$ are the protection factors for the first, second,...,nth exercises.

Other laboratories use different definitions. LANL uses the definition [8]

$$\langle PF \rangle = 1/(1/N[P_1 + P_2 + \ldots P_N]) \tag{3}$$

where $P_1, P_2, \ldots, P_N$ are the penetration concentration (as a fraction of the challenge concentration) for each exercise.

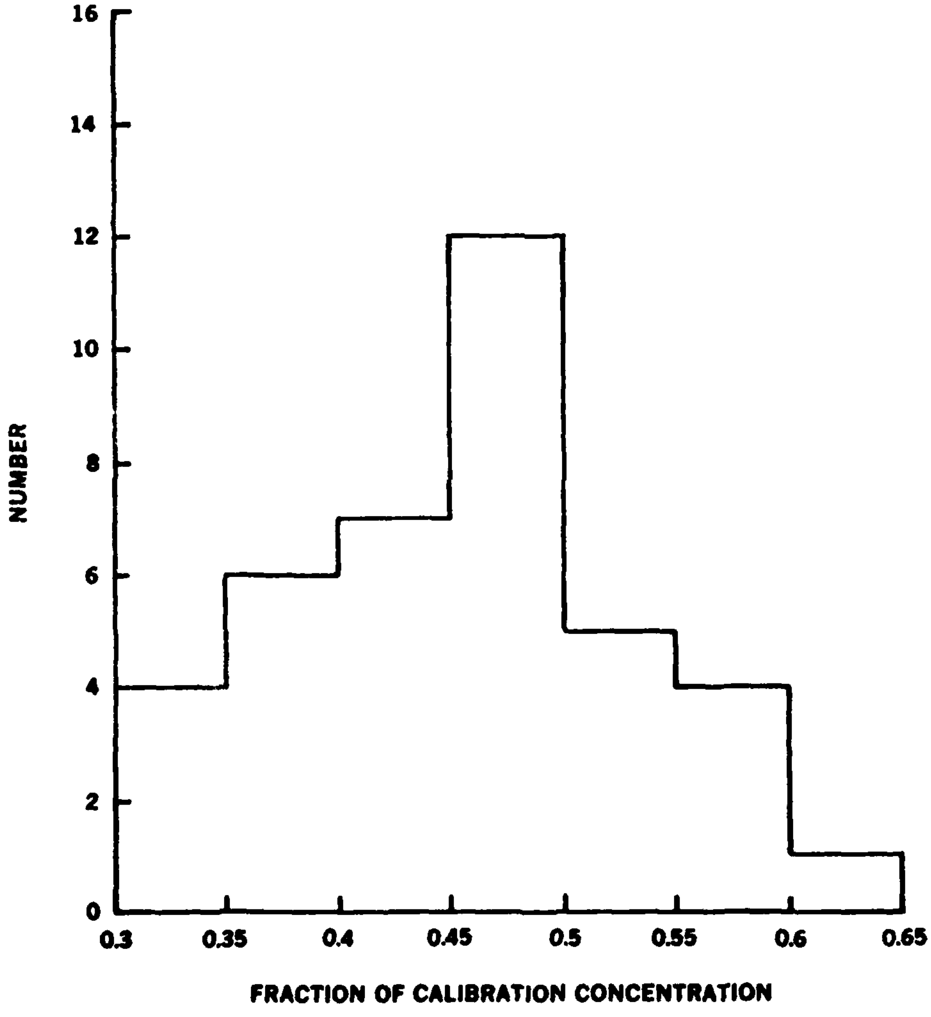

Figure 2. Histogram of 39 observations of test-tent concentration as a fraction of calibration concentration. ("Number" = observations per interval)

Lawrence Livermore National Laboratory (LLNL) uses the definition [9]

$$\langle \log P_g \rangle = (\log P_1 + \log P_2 + \ldots \log P_N)/N \tag{4}$$

where the antilog of $\langle P_g \rangle$ is the geometric mean penetration;
$\log P_1, \log P_2, \ldots \log P_N$ are the logarithms of penetrations for N exercises; and

$$\langle PF \rangle = 1/\langle P_g \rangle \tag{5}$$

where P_g is a fraction of the challenge concentration.

MEASURES OF CENTRAL TENDENCY

Averages are measures of the central tendency of a set of data and, with a standard deviation, are used to summarize the magnitude and dispersion of the individual data points. The most commonly used average is the arithmetic mean (Equations 2 and 3). A less commonly used average is the geometric mean (Equation 4). When data are normally distributed, their arithmetic mean is representative of the data. If the data are log-normally distributed, the geometric mean is appropriate. Two recent studies done at LLNL have emphasized that PF data are more nearly log-normal than normal distributions [9,10]. Myers and Peach [11] have also reported geometric mean PFs.

REPRESENTATIVE AVERAGE PROTECTION FACTORS

An average PF should be representative of the protection provided by the personal protective equipment. Table 1 illustrates the average PF obtained by the methods defined in Equations (2-5). Two simple examples are shown. The arithmetic mean PFs obtained from Equations (2) and (3) are not equivalent; the average obtained by Equation (2) is significantly greater under certain conditions. The average obtained from Equation (2) is weighted toward high

TABLE 1. AVERAGE PROTECTION FACTOR OBTAINED BY THREE METHODS OF AVERAGING

	High leakage		Low leakage	
Exercise	Fraction	PF	Fraction	PF
1	.000001	10^6	.0001	10^4
2	.0001	10^4	.000001	10^6
3	.0001	10^4	.000001	10^6
4	.0001	10^4	.000001	10^6
5	.0001	10^4	.000001	10^6
"Average PF"	2.0×10^4 [a]	1.75×10^5 [b]	5.7×10^4 [a]	8.35×10^5 [b]
Geometric mean	2.2×10^4 [c]	2.2×10^4 [c]	4.6×10^5 [c]	4.6×10^5 [c]

[a] Mean PF calculated from Equation 3.
[b] Mean PF calculated from Equation 2.
[c] Mean PF calculated from Equations 4 and 5.

protection (1.75×10^5) by one low-leakage measurement (.000001). The average obtained from Equation (3) is weighted toward low protection (5.7×10^4) by one high-leakage measurement (.0001). The geometric means (2.2×10^4 and 4.6×10^5) lie between the two arithmetic means. In this special case the geometric mean PF from penetration and the geometric mean PF calculated from exercise PFs are equivalent.

The average obtained from Equation (3) will always be lower than that obtained from Equation (2) and can be defended as a conservative measure of protection. There are no apparent advantages to the use of Equation (2) for reporting average PFs. The geometric means are more representative of these data than the arithmetic means because each value in the means has equal weight in determining the average [12].

Table 2 shows the minimum and maximum PF for 40 data sets of six exercises each, also the average PFs as calculated by Equations (2), (3), and (4). The two arithmetic average PFs differ by about a factor of 2 when the value of all six exercise PFs, or leakages, fall within one order of magnitude. Greater discrepancies exist when the range of PFs for the exercises is greater than an order of magnitude. The averages calculated by Equation (2) are greater than or equal to the averages calculated by Equation (3). The geometric averages fall between the two arithmetic averages.

The arithmetic and geometric means of each column of average PFs is shown at the bottom of Table 2. In all cases the arithmetic mean exceeds the geometric mean by one order of magnitude or more.

TABLE 2. AVERAGE PROTECTION FACTOR OBTAINED BY THREE METHODS OF AVERAGING (FORTY DATA SETS OF SIX EXERCISES EACH)

Data set	Minimum PF	Maximum PF	Arithmetic average [a]	Arithmetic average [b]	Geometric average [c]
1	6.0E+03[d]	5.4E+05	2.8E+05	2.3E+04	8.9E+04
2	2.9E+03	1.0E+06	5.4E+05	9.8E+04	2.6E+05
3	1.6E+02	5.1E+05	1.7E+05	8.4E+02	1.2E+04
4	9.7E+02	2.3E+04	1.0E+04	3.9E+03	7.2E+03
5	1.0E+02	2.4E+02	1.7E+02	1.5E+02	1.6E+02
6	5.0E+02	4.6E+03	2.0E+03	1.1E+03	1.5E+03
7	1.4E+01	2.6E+01	2.2E+01	2.1E+01	2.1E+01
8	2.6E+00	5.1E+00	4.1E+00	3.9E+00	4.0E+00
9	7.8E+01	2.0E+03	9.8E+02	3.2E+02	6.6E+02
10	7.9E+01	9.0E+04	2.3E+04	4.5E+02	5.2E+03
11	1.4E+01	1.2E+02	5.4E+01	3.1E+01	4.2E+01
12	4.6E+02	5.7E+03	1.8E+03	8.9E+02	1.2E+03
13	1.8E+02	3.9E+03	1.2E+03	5.4E+02	7.9E+02
14	1.4E+02	5.4E+02	3.2E+02	2.6E+02	2.9E+02
15	3.6E+02	2.0E+03	9.1E+02	6.8E+02	7.8E+02
16	6.8E+01	9.5E+02	3.8E+02	2.1E+02	2.9E+02
17	3.8E+02	1.2E+03	6.5E+02	5.6E+02	6.0E+02
18	1.5E+03	5.9E+03	3.2E+03	2.6E+03	2.8E+03
19	6.2E+02	5.3E+03	2.0E+03	1.2E+03	1.5E+03
20	2.0E+02	4.0E+03	9.5E+02	3.2E+02	4.6E+02

TABLE 2 (Continued).

Data set	Minimum PF	Maximum PF	Arithmetic average [a]	Arithmetic average [b]	Geometric average [c]
21	2.7E+01	8.3E+01	4.5E+01	3.8E+01	4.1E+01
22	4.4E+02	3.2E+04	1.1E+04	2.0E+03	5.4E+03
23	2.1E+01	1.0E+03	3.7E+02	8.2E+01	2.0E+02
24	1.7E+01	2.5E+02	9.8E+01	4.4E+01	6.6E+01
25	1.1E+02	7.8E+02	3.0E+02	2.0E+02	2.4E+02
26	2.5E+01	9.1E+01	4.9E+01	4.1E+01	4.5E+01
27	1.4E+04	3.6E+05	1.9E+05	3.5E+04	8.3E+04
28	1.3E+02	2.5E+02	1.7E+02	1.6E+02	1.6E+02
29	3.4E+01	8.2E+01	5.9E+01	5.4E+01	5.6E+01
30	1.5E+01	4.3E+01	2.9E+01	2.3E+01	2.5E+01
31	4.8E+03	4.9E+05	2.5E+05	1.8E+04	7.5E+04
32	5.5E+01	1.1E+02	9.0E+01	8.5E+01	8.7E+01
33	9.2E+01	7.6E+02	2.4E+02	1.5E+02	1.8E+02
34	9.8E+01	1.7E+02	1.3E+02	1.3E+02	1.3E+02
35	9.4E+01	8.7E+02	2.5E+02	1.4E+02	1.7E+02
36	1.1E+02	4.2E+02	2.4E+02	2.0E+02	2.2E+02
37	3.7E+01	1.5E+02	9.9E+01	8.0E+01	9.0E+01
38	8.0E+01	1.3E+02	1.1E+02	1.0E+02	1.0E+02
39	1.1E+01	2.5E+01	1.6E+01	1.4E+01	1 5E+01
40	7.6E+00	2.0E+01	1.4E+01	1.2E+01	1.3E+01
	Arithmetic mean		3.7E+04	4.8E+03	1.4E+04
	Geometric mean		6.4E+02	2.8E+02	4.3E+02

[a] Calculated from Equation (2).
[b] Calculated from Equation (3).
[c] Calculated from Equation (4).
[d] $6.0E+03 = 6.0 \times 10^3$.

Figure 3 shows a histogram of the geometric means of six exercises for 40 test subjects; Figure 4, a histogram of the arithmetic means of the same data. The frequency distributions in Figures 3 and 4 cannot be characterized as either normal or log-normal distributions [13]. Thus, there is no statistical justification (based on these data) for either an arithmetic or geometric mean being a valid representation of central tendency. The geometric mean, however, is more representative of the apparent central tendency of these data than the arithmetic mean.

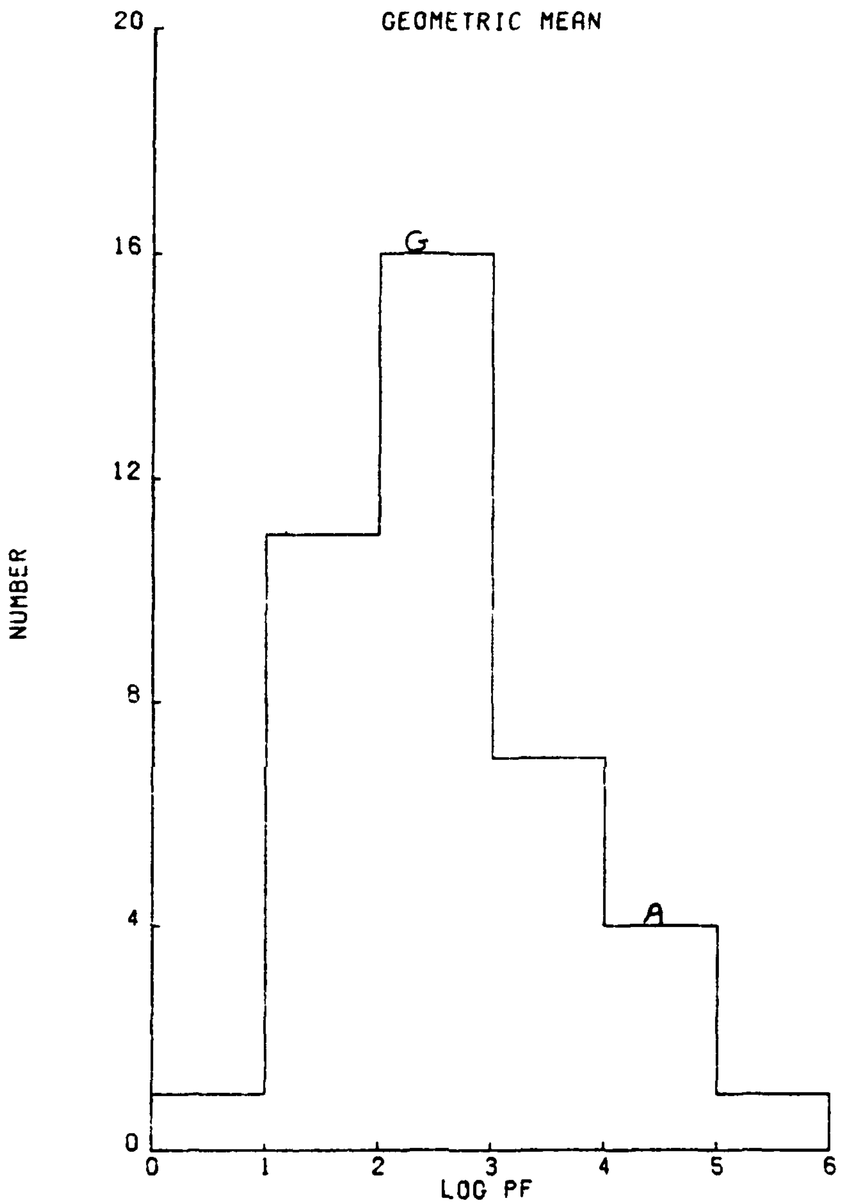

Figure 3. Histogram of 40 geometric means, six exercises each. (G = geometric mean; A = arithmetic mean)

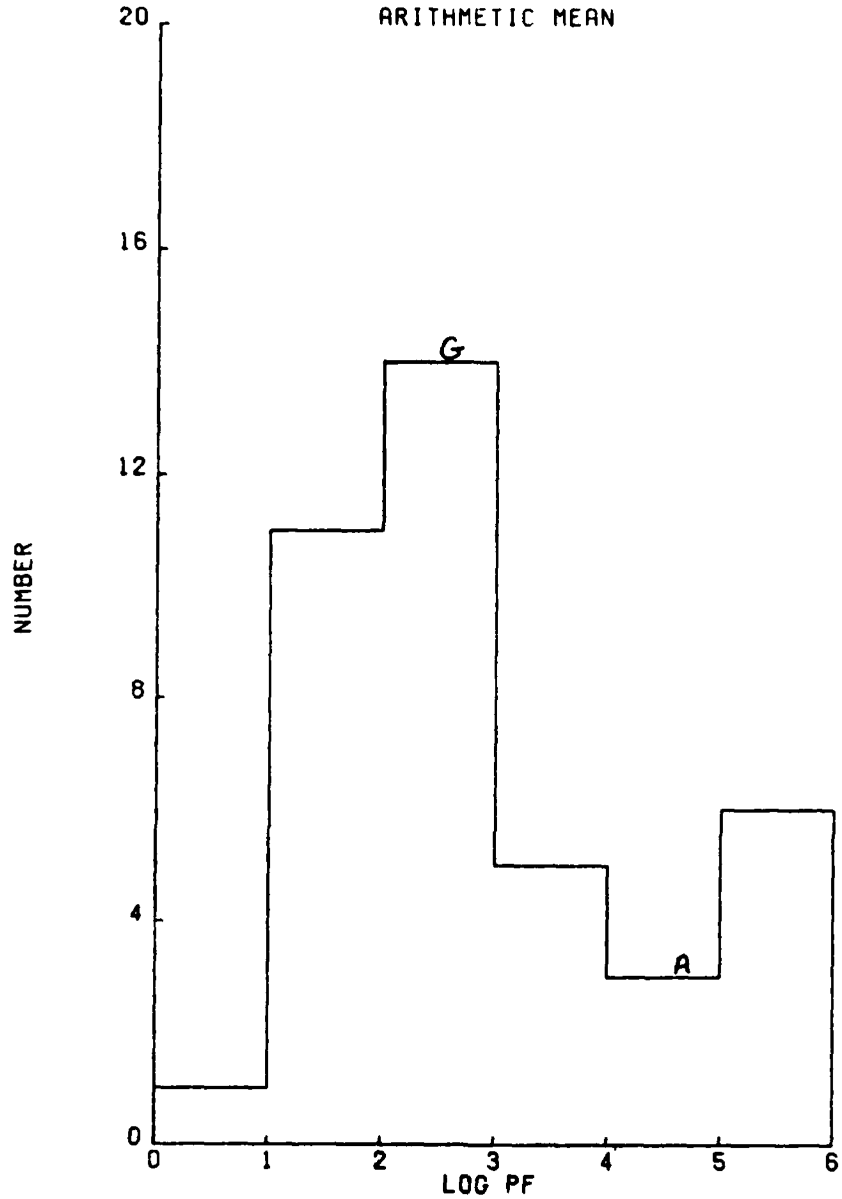

Figure 4. Histogram of 40 arithmetic means, six exercises each. (G = geometric mean; A = arithmetic mean)

CONCLUSIONS

Reevaluation of the USAFSAM Respirator Quantitative Fit Test methods, procedures, and data analyses indicates that the omission of test-tent sampling and the method of averaging PF data over six or more exercises can result in average respirator PFs that differ from those of other laboratories by a factor of 4 or more.

Revised RQFT procedures at USAFSAM include sampling from the test tent to establish challenge-concentration equilibrium and compensate for aerosol line loss. Three average protection factors, $\langle PF_1 \rangle$, $\langle PF_2 \rangle$, and $\langle PF_3 \rangle$, are now calculated, where

$$\langle PF_1 \rangle = (1/N)(PF_1+PF_2+\ldots PF_N), \quad \text{(Eq 2')}$$

$$\langle PF_2 \rangle = 1/([1/N][P_1+P_2+\ldots PN]), \quad \text{(Eq 3')}$$

$$\langle PF3 \rangle = 1/\log^{-1}([\log P_1+\log P_2+\ldots \log PN]/N) \quad \text{(Eq 4')}$$

(Equation 4' is derived from both Equations 4 and 5). These changes should remove a source of error from USAFSAM protection-factor data and facilitate comparison of our results with those of other laboratories.

None of the average PFs is "correct." The discrepancies, however, indicate the urgent need for a standard definition of "average protection factor." Efforts to determine the underlying frequency distribution of PF data will continue so that statistically appropriate means and other statistics can be calculated.

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